PHYSICAL-CHEMICAL INTERACTIONS AT METAL/LOW-K DIELECTRIC INTERFACES

by

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ABSTRACT

Copper drift induced dielectric breakdown is a major reliability issue in current back-end-of-line interconnects. The ITRS roadmap requirement for thinner barriers will exacerbate this problem and a fundamental study of this phenomenon needs to be performed to thoroughly understand it.

A mechanism of copper charge injection that links the interfacial oxidation of copper is proposed and experimentally tested. We then propose a mathematical model of copper ion drift/diffusion through dense dielectrics which involves the time dependent solution of the non-linear Continuity and Poisson equations. The choice of a "blocking" electrode boundary condition ($J(t,L)=0$) is shown to be the right one to use at the cathode as it matches experimental data. We use the model to compute the time taken for the copper ions to increase the internal electric field at the cathode to the breakdown strength of the dielectric (in this case for thermal SiO_2).

We propose an equation which calculates the time to failure (TTF) of the dielectric combining the intrinsic breakdown of the dielectric through bond breakage (after the 'E-model') and our mass transport induced field increase at the cathode from our model. This new equation matches all available experimental TTF data on $Cu/SiO_2/Si$ devices with a minimum of parameters. Solubility of copper ions in the dielectric is identified as an important parameter in causing dielectric failure. We show that the induced dipole moment energy of the copper ions plays an important part in the intrinsic breakdown and leads to an E^2 dependence of ln (TTF).

We incorporate a new 'elastic' drift term in the continuity equation to account for the high concentrations of copper ions seen at the cathode at failure. This new formulation leads to important results for reliability of devices with a threshold value of the applied voltage where breakdown may not be occurring due to metal ion induced field enhancement.